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Optical Specifications – Their Role in the National Ignition Facility

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Optical specifications – their role in the National Ignition Facility

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Abstract: The National Ignition Facility (NIF) has completed its design phase and is well into construction. In this talk, we review the optic specification rationale, along with examples of particular specifications and measurements.

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1. Introduction

The National Ignition Facility (NIF) [1] has completed its design phase and is well into construction. The pilot fabrication runs for the large aperture optics are nearing completion and the procurement of the small optics required for the injection laser system (ILS) has begun. This brings the initial development and documentation of the optical specifications to a close and begins a maturation process based on evolution of requirements, results of the pilot runs and vendor feedback. While minor details of the optic specifications have changed, the basic specification rationale remains unaltered. This rationale will be reviewed, along with examples of particular specifications and measurements.

2. Overview of optical specifications and their maintenance

Optical specifications, as detailed in the optic drawing used in procurement, are numerous and diverse. Many are basic, such as dimensions and tolerances. Others are more difficult to understand, such as detailed wavefront specifications. Regardless of the complexity of the specification, each one plays a part in assuring the performance of NIF. Detailed optic drawings now exist for all NIF optics and are under configuration management control. This means that all proposed changes must be documented in an approved engineering change request (ECR) and their impact on the project detailed before the change is adopted. The diligent maintenance of the many optical specifications is critical to the project; to insure compatibility of optics and mounts, to prevent unwanted optical damage, and to insure laser performance. Foremost in importance for achieving NIF's primary criteria (i.e., the basic requirements of power and focusability)[2] are the specifications on the optic wavefronts.

3. Wavefront specification rationale

3.1 Choice of metrics

The majority of optical wavefront specifications for NIF are derived either from their impact on the output of the laser system or from risk of optical damage at high power operation. For convenience, the NIF optics can be classified into two general types, large optics and small optics, that are treated differently for specifications purposes because of their differing impact on the laser performance. In the process of modeling the effects of wavefront error on laser performance, we have found that the traditional metrics of peak-to-valley and root-mean-square (rms) wavefront are not adequate, especially with the advent of new manufacturing techniques that produce non-traditional phase statistics. Therefore, we have developed optic specifications that can be directly linked to aspects of laser performance[3-4].

It can be shown that for spot sizes many times diffraction limited the spot size is well described by geometrical optics[5]. In that representation, the spread of ray angles determines the spot size. The analog of a ray angle in wave optics is the slope or gradient of the wavefront. Thus, a natural metric for controlling final spot size is the rms of the wavefront gradients. Unfortunately, the rms gradient is sensitive to instrument noise and surface roughness, neither of which will strongly influence the spot size. In order to remove this limitation, we allow the wavefront to be low-pass filtered over the spatial frequencies characteristic of the spot and assign the filtered rms gradient as our primary metric to control focusability for both the large and small NIF optics.

In high power, solid-state lasers, an additional complication arises. Characteristic spatial frequencies see non-linear growth that can degrade the spot size and generate intensity modulations that damage the laser optics[6]. To prevent this, we need to limit the presence of these spatial frequencies. A well-suited metric is the power-spectral density (PSD) function[7-9]. The PSD is the squared magnitude of the Fourier transform of the wavefront, scaled such that the area under the PSD is the squared rms of the wavefront. We have adopted the PSD as our primary metric to control non-linear ripple in the large NIF optics.

3.2 Spatial frequency regimes

The small optics most strongly influencing the laser performance are those in the injection laser system (ILS) which generates the pulses that are injected into the 192 NIF beamlines[10]. Because the fluences present in the ILS are sufficiently low that non-linear processes and associated damage are not generally an issue in that section of the laser chain, specifications are most critical over those spatial frequencies that will be transmitted to the main laser chain. The rms gradient for the main laser chain is defined for spatial scalelengths up to 33mm. Due to the difference in beam size between the ILS and the main laser chain, this becomes a specification for spatial scale lengths up to 2.7 mm in the power amplification module (PAM) and input sensor package (IPS) and up to 4.0 mm in power amplifier beam splitter telescope (PABST). Currently, we are specifying over a single, slightly broader spatial wavelength range for convenience and to allow some margin for design modifications. We have defined the spatial wavelength cutoff at 2mm for all optics in the ILS. Table 1 summarizes the spatial frequency regimes and the primary metric that is used there.

Type of optic	Scalelengths	Name of wavefront error regime	Controlling metric
Small optics	DC – 2mm 2mm – 15μm	Figure Waviness	rms gradient rms
Large optics	DC – 33mm 33 – 2.5 mm 2.5mm – 120μm 120 – 10 μm	Figure Waviness-1 Waviness-2 Roughness	rms gradient PSD PSD rms

3.3 Spatial filtering considerations

Since the rms gradient is specified over a range of spatial scalelengths, spatial filtering plays a central role in the specification verification. Unfortunately, there exist some concerns over how commercial intereferometry software handles spatial filtering. If care is not taken to minimize the effects of Gibbs modulation, filtered interferograms can display more modulation than the original data. Windowing or other techniques to minimize the artifacts that sometimes accompany spatial filtering must also mitigate the effect of finite sampling. Lastly, the way dropouts and no-data regions are handled can also effect the results. For these reasons, we have created post-processing routines to test the effect of commercial software algorithms on the values calculated for the rms gradient and power spectral density (PSD). Since the PSD is highly sensitive to the nature of the algorithm used and is a critical specification for the large aperture optics, we have decided to use custom post-processing software to verify compliance of NIF large aperture parts with the wavefront specifications. In the case of small optics, however, we have instead decided to use commercial software capabilities with specific instructions on the way that the specifications are to be verified. Low-pass spatial filtering of the interferogram with a cutoff wavelength of 2mm will be done before computation of the rms gradient. The filtering algorithm used must be demonstrated to produce no artifacts that would alter the calculation of the rms gradient.

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5. References

1. *National Ignition Facility Conceptual Design Report,* NIF-LLNL-94-114, Lawrence Livermore National Laboratory, Livermore, California, May 1994.
2. *NIF Functional Requirements and Primary Criteria*, L-15983-3, , Lawrence Livermore National Laboratory, Livermore, California, March 20, 1996.
3. D. M. Aikens, "The origin and evolution of the optics specification for the National Ignition Facility", *Optical Manufacturing and Testing,* Proc. SPIE Vol. 2536, pp. 2-12, 1995.
4. J. K. Lawson, et.al., "NIF Optical Specifications – The Importance of the RMS Gradient Specification", *Proceedings of the Solid State Lasers for Applications to Inertial Confinement Fusion Third Annual Conference,* Monterey, California, Proc. SPIE Vol. 3492, pp. 336-343, 1998.
5. Warren J. Smith, *Modern Optical Engineering – The Design of Optical Systems, 2nd Ed.*, (McGraw Hill, New York, New York, 1990), pp.356-360.
6. J. B. Trenholme, "Theory of irregularity growth on laser beams", *1975 Annual Report*, UCRL-50021-75, Lawrence Livermore National Laboratory, Livermore, California,(1975), pp.237-242.
7. E. L. Church, T.V. Vorburger and J.C. Wyant, "Direct comparizon of mechanical and optical measurements of the finish of precision machined optical surfaces", Optical Eng., v. 24, no. 3, pp. 338-395,(1985).
8. J.M. Elson and J. M. Bennett, "Calculation of the power spectral density from surfae profile data", Applied Optics, v. 34, no. 1, pp. 201-208, (1995).
9. C.J.Walsh, et.al., "Power spectral density analysis of optical substrates for gravitational-wave interferometry", Applied Optics, Vol. 38, No. 22, pp. 4790-4801, 1999.
10. D. M. Aikens, "National Ignition Facility small optics overview", *Optical Manufacturing and Testing III*, SPIE International Conference on Optical Science Engineering and Instrumentation, Denver, Colorado, July 18-23,1999, to be published.